Iris Device Qualification Test (IDQT) Workshop

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Session Organization

- Motivation and Purpose of Test
- Goals of this Presentation
- Review of IDQT
- Review submitted comments and editor's disposition
- "Feel of the Room" for possible areas of document change

Motivation

- To develop an effective process for the evaluation and qualification of iris biometric cameras
- Fulfill the near term needs for the Air Exit and Entry Reengineering (AEER) project (see to slides and handout for more details)

Motivation

Iris Device Qualification Test

Certified List for DHS Applications

Iris Biometrics: A Complex Multivariate System

Examples of Covariates which can influence iris Image Quality

Device Covariates (recording optical signals)

- Spatial Frequency Response
- Throughput/Quantum Efficiency
- Illumination (photon noise)
- Dynamic Range and Resolution
- Field Distortion
- Capture Volume
- Ambient Light Mitigation
- Detector Noise

Device Covariates (Human Factors Control)

- Gaze attractor
- Pupil dilation control
- Eyelid occlusion filter/ control
- Subject Motion Control
- Physical ergonimics of Device
- Software interface

Human Subject Covariates

- Eye Gaze
- Blinking/Squinting
- Pupil Dilation
- Ease of operation
- Subject motion
- Intrinsic signals (iris features, boarder contrasts and shapes, skin tones)
- Eye diseases
- Range of Pupil Dilation
- Habituation

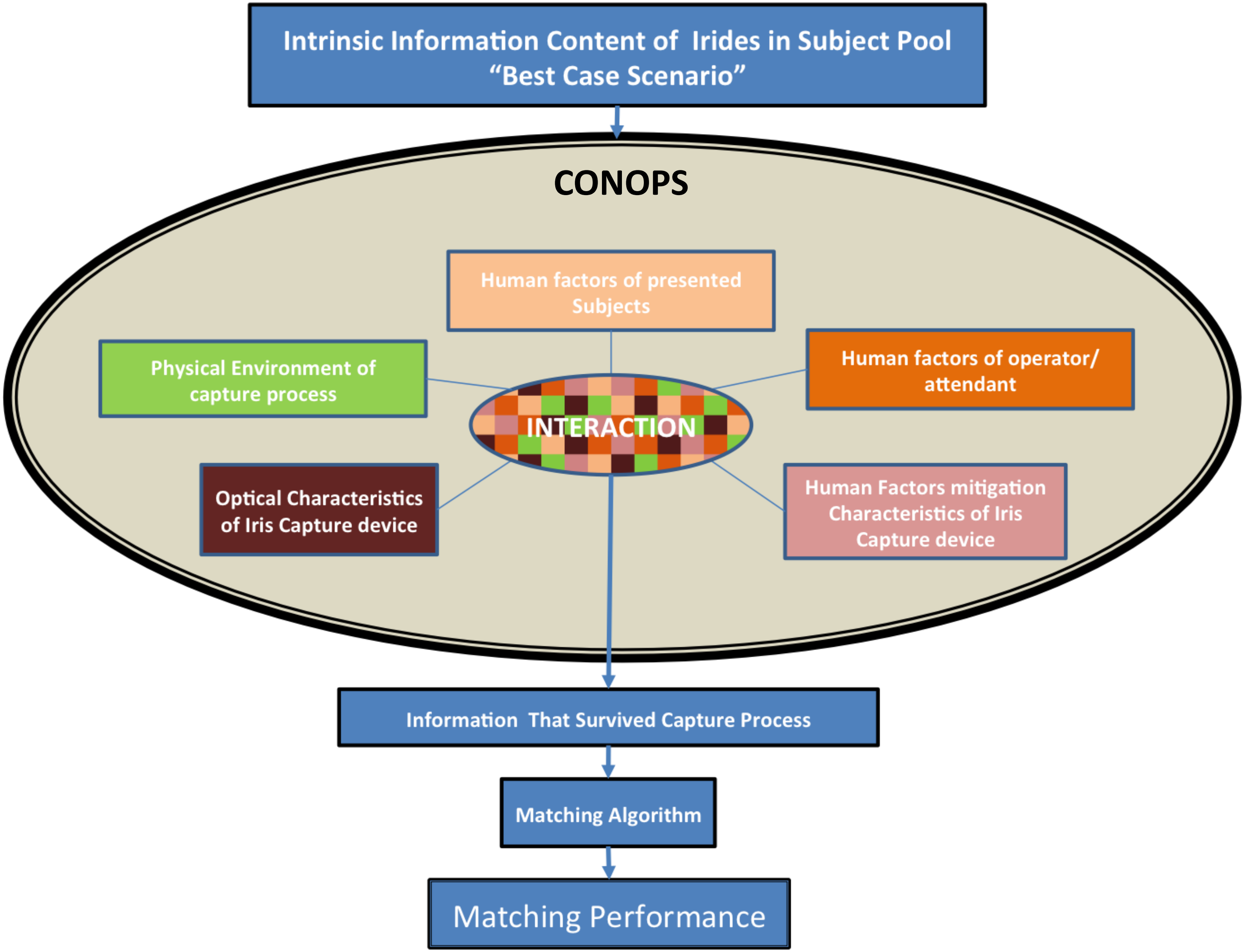
Human Operator Covariates

- Past Experience with device
- Mental abilities
- Physical abilities

Environmental Covariates

- Ambient Illumination
- Vibration
- Temperature/Humidity
- Sound environment

CONOPS


Intrinsic Information Content of Irides in Subject Pool
"Best Case Scenario"
CONOPS
Human factors of presented Subjects
Physical Environment of capture process
Human factors of operator/ attendant
INTERACTION
Optical Characteristics of Iris Capture device
Human Factors mitigation Characteristics of Iris Capture device
Information That Survived Capture Process
Matching Algorithm
Matching Performance

IDQT Rationale: Divide the Problem

Human Interaction aspects tested with Humans, not in the IDQT

Device Covariates (recording optical signals)

- Spatial Frequency Response
- Throughput/Quantum Efficiency
- Illumination (photon noise)
- Dynamic Range and Resolution
- Depth of Field
- Capture Volume
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CONOPS

IDQT CONSIDERS ASPECTS OF QUALITY INDEPENDENT OF HUMAN INTERACTION

DHS Evaluation Process

Market Survey

Device Qualification

IDQT acts as a filter so time is not wasted evaluating devices with human subjects

Human-in-the-loop Laboratory Performance Qualification

Pilot Integration

Field trials

Human interaction issues are evaluated just on the devices which pass the IDQT

Final Integration and Deployment

Project Goals

Develop “Appendix F-like” iris device qualification testing tools and procedures which:

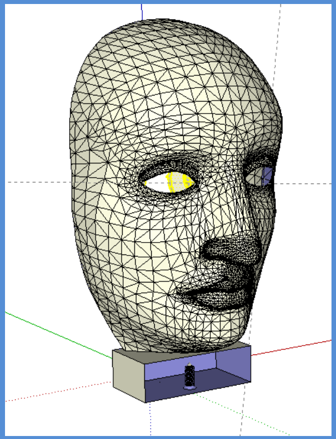
1. Minimize biases between devices
2. Minimize modification to intended device operation on real human subjects
3. Measure “peak” imaging performance… degradation from realistic operations should be revealed in subsequent evaluation stages
4. Should be simple enough to be practically conducted by a third party testing facility

Goals of this Session

- Present Overview of IDQT
- Point out areas of possible change to draft based on comments from industry
- Review received comments and editor's disposition
- Discuss possible changes, get the "feel of the room"
  - No contention
  - Acceptable, but could be improved
  - No acceptable, introduces significant bias and or would produce severely misleading guidance

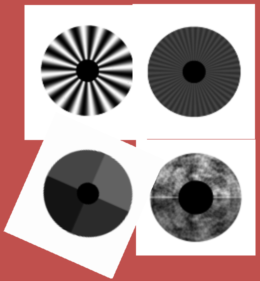
Development Components

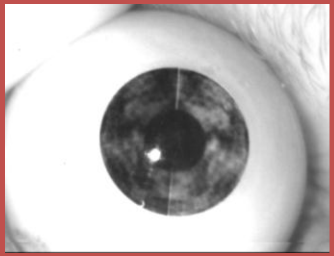
Face Foundation



- Passes face recognition requirements of capture devices
- Mimics light reflection from human skin
- Accurate, precise optical mount for eye targets

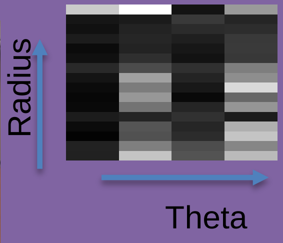
Targets/Algorithms

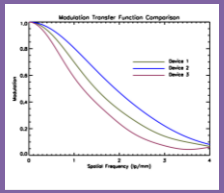




- Passes "eye-ness" requirements of capture devices
- Contains known patterns used for diagnostic measurements
- Mounts into face foundation

Test Plan/Reporting





- Well documented procedure to validate test targets, collect and analyze data
- Standardized output of results for meaningful inter-device comparisons

Overview of Metrics Recorded in IDQT

IDQT Image Quality Measurements

Qualification Criteria

1. Spatial Frequency Response
2. Iris-like Feature SNR

Used in 'root cause' estimation

1. Pixel Scale (all targets)
2. Greyscale Linearity
3. Greyscale Resolution
4. Field Distortion

IDQT Device Characterization

Qualification Criteria

1. Illumination: Eye Safety

Environment Categories

2. Cornea Reflection Mitigation: Ambient Scene
3. Cornea Reflection Mitigation: Instrument only

Mobile ID Guideline

1. Illumination: Wavelength Characterization
2. Exposure Time Estimation

Rationale for Qualification Criteria

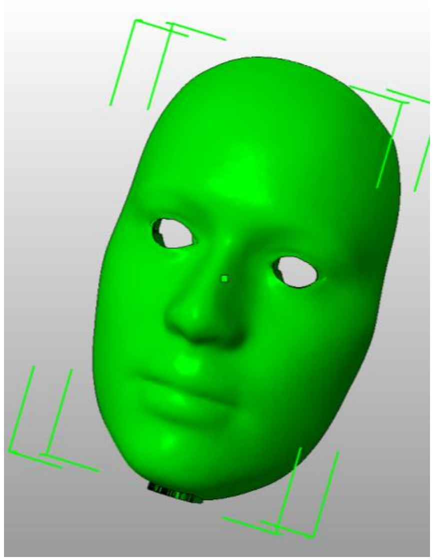
Complicated approach:

Assign individual criteria for a list of individual and combinations of metrics. Requires extensive controlled studies correlating individual metrics.

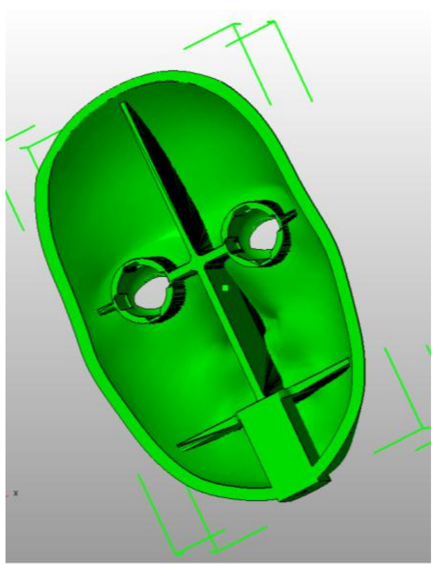
More practical 'bottom line' approach:

Characterize signal used in iris biometrics, reproduce signal in static targets, encode and match features like commercial algorithms to define quality metric

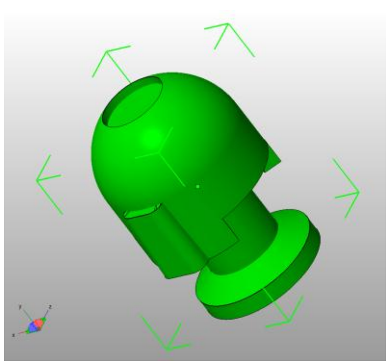
IDQT Face Design



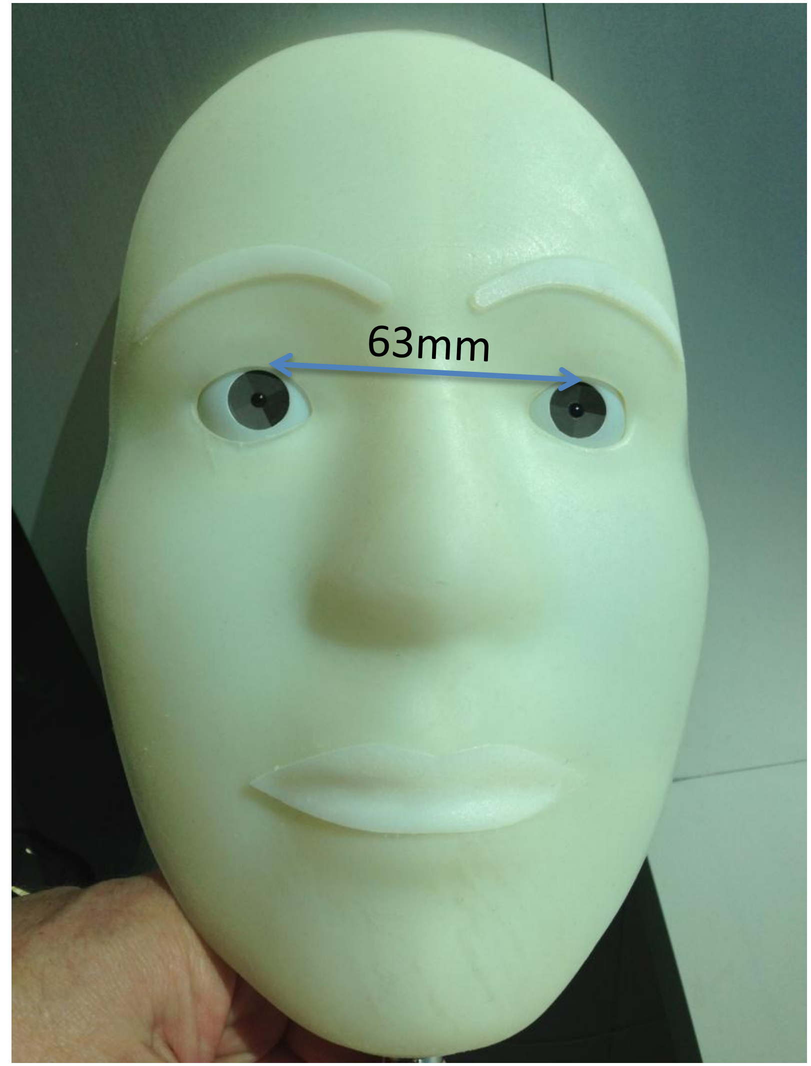
Front surface
“average” 3-D face
IPD=63mm (average)



Back surface
accommodates
eyeball mounting



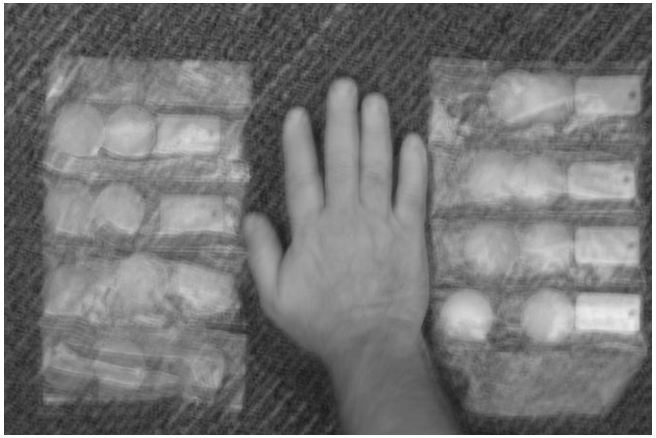
Eyeball mount
for iris targets



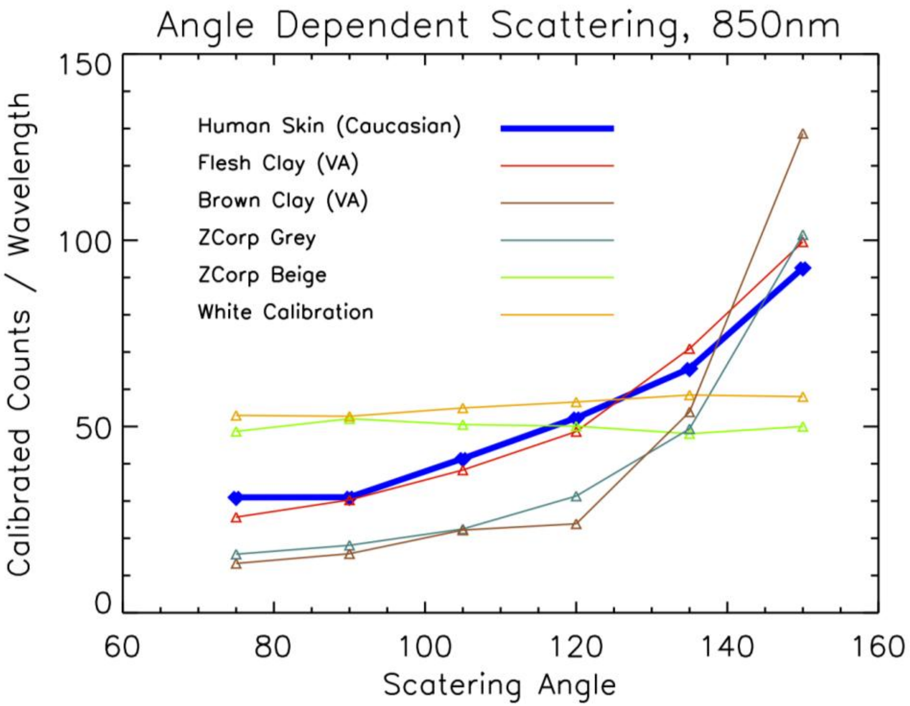
3-D Printed Model

Face Material Study: Search for skin-like NIR BRDF

Goniospectrophotometer

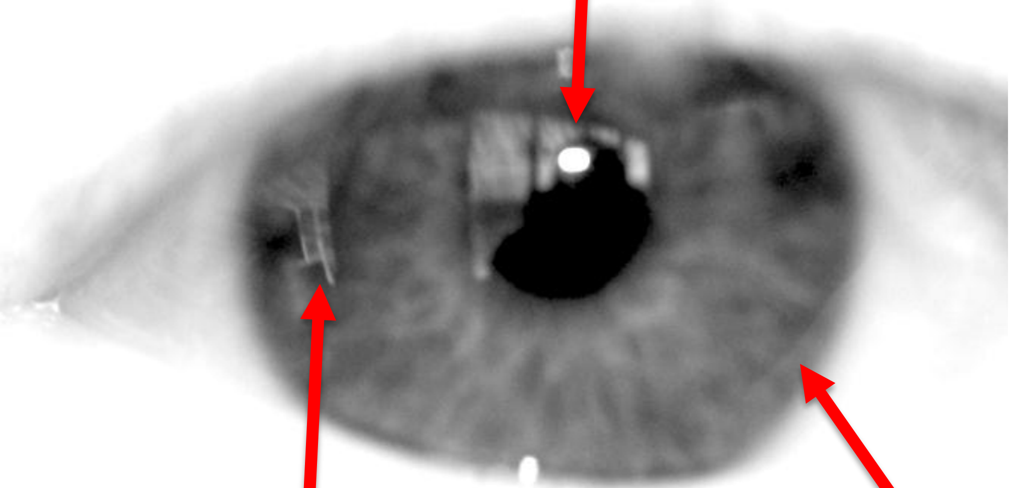


Near Infrared Image of Material Samples



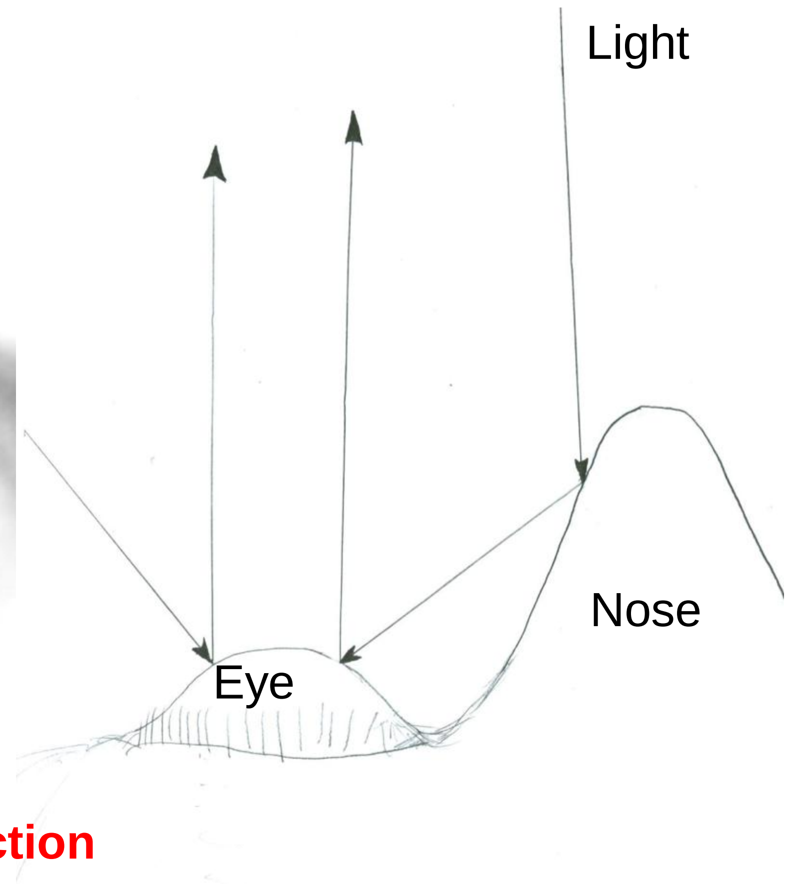
Corneal Reflections

Primary Illuminator Reflection



Nose Reflection

Ambient Light Reflection

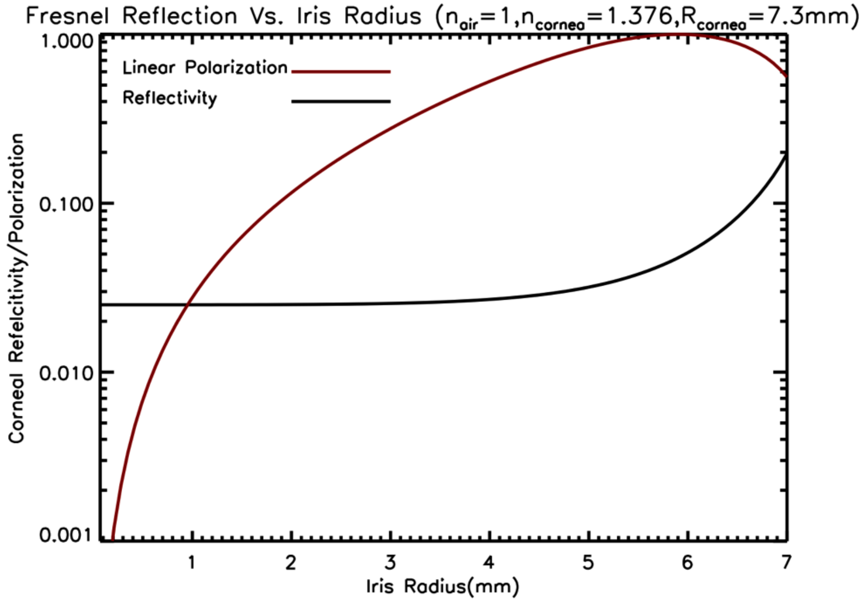


Face Discussion Issues

Suggested IDQT uses average characteristics of face morphology and skin tone.

COMMENTS:

- Argument to incorporate multiple faces with different morphologies to explore extremes of scale (Include children and large end outliers)
- Argument to incorporate multiple skin tones (e.g. test for face detection failure)

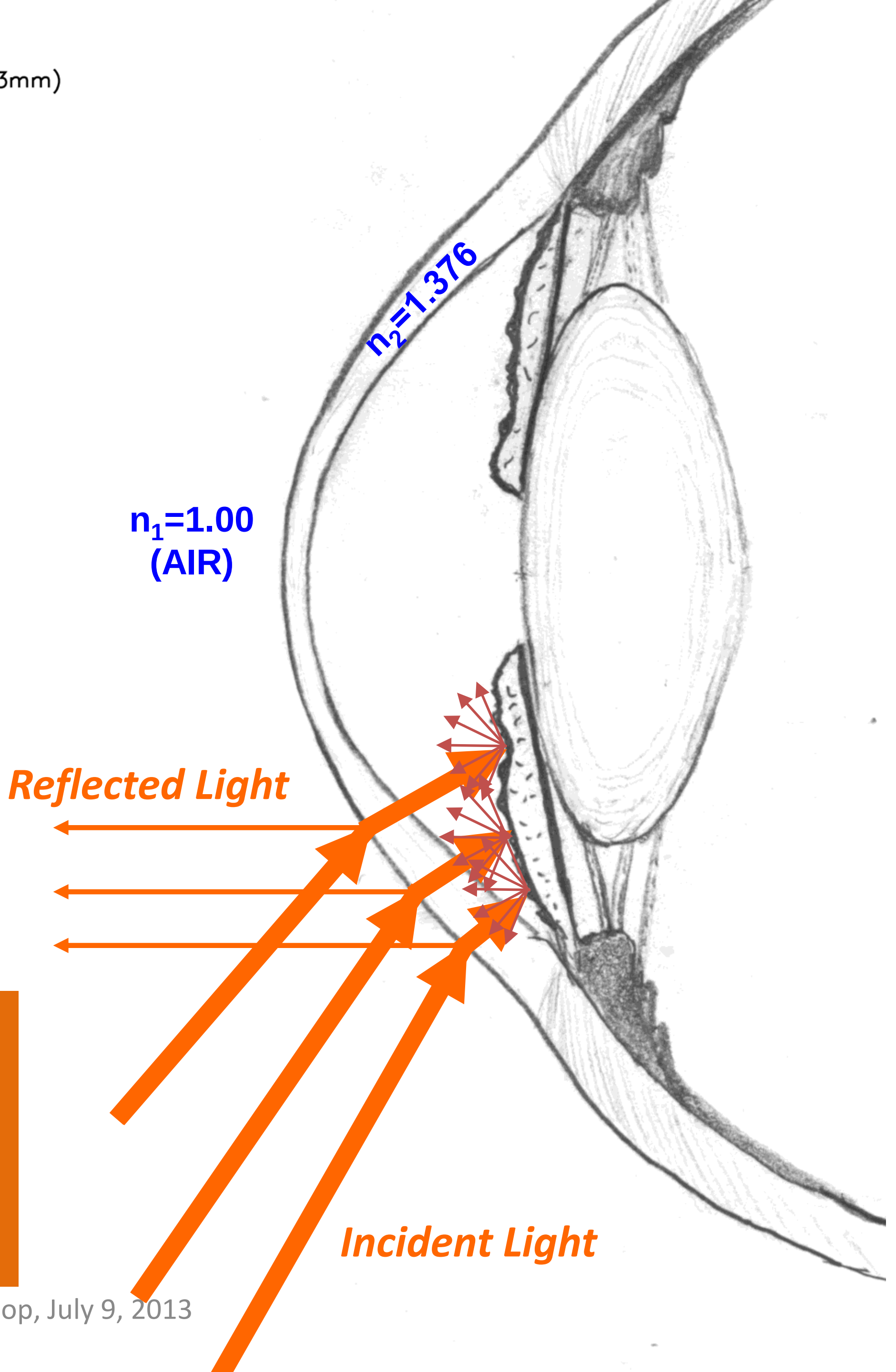


<u>Cornea surface (Strict Fresnel)</u>

- Reflects ~2-3% of incident NIR light
- Fish-eye de-magnification
- Polarized

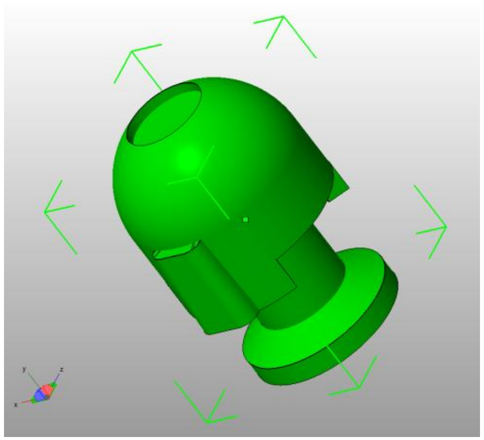
<u>Iris surface</u>

- Scatters ~10-16% of incident NIR Light
- Lambertian?



Eye target Development

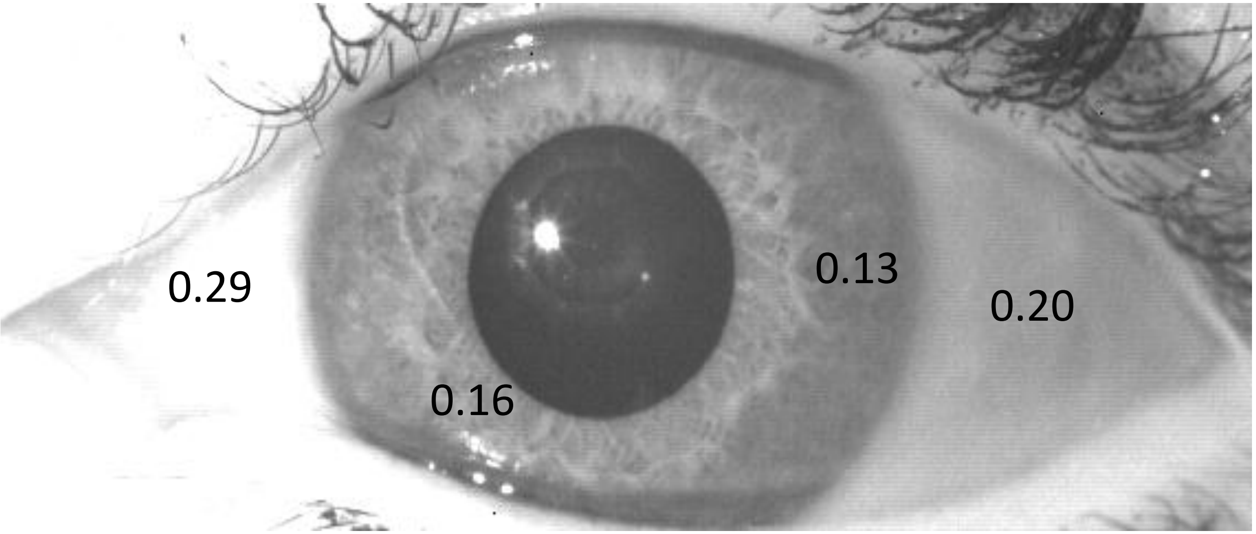
- Diameter of iris piece=11.8mm, ball diameter=25mm
- Lens surface provides cornea-like reflection (calibrated to real human examples)
- Index match on opaque backside for minimal back surface reflection
- Front Lens Radius of Curvature = 7.85mm (human cornea is aspheric, ranges from ~7-8mm)



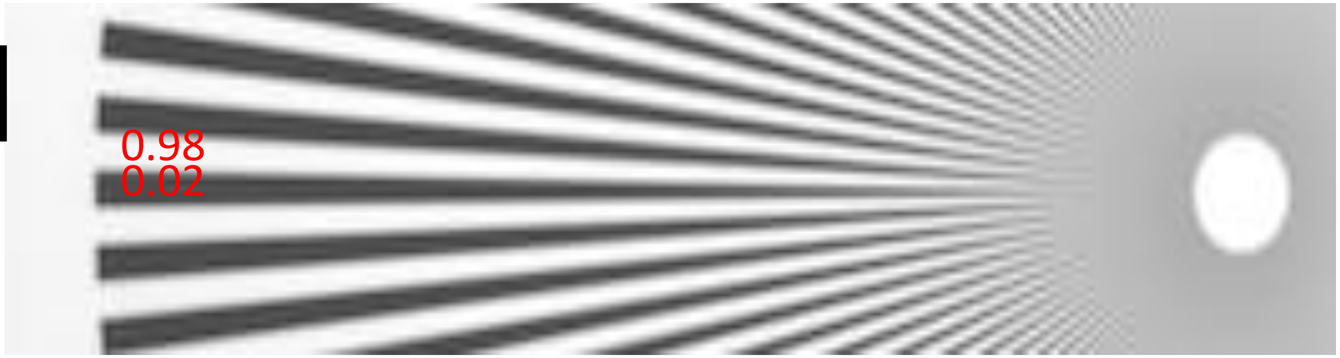
Rationale: Capture Optical Traits of Human Eye

Reflectivity Numbers Overlaid

Brown Eye



Typical CTF Target



Iris Signal Characterization

What is there:

Features < 10 microns

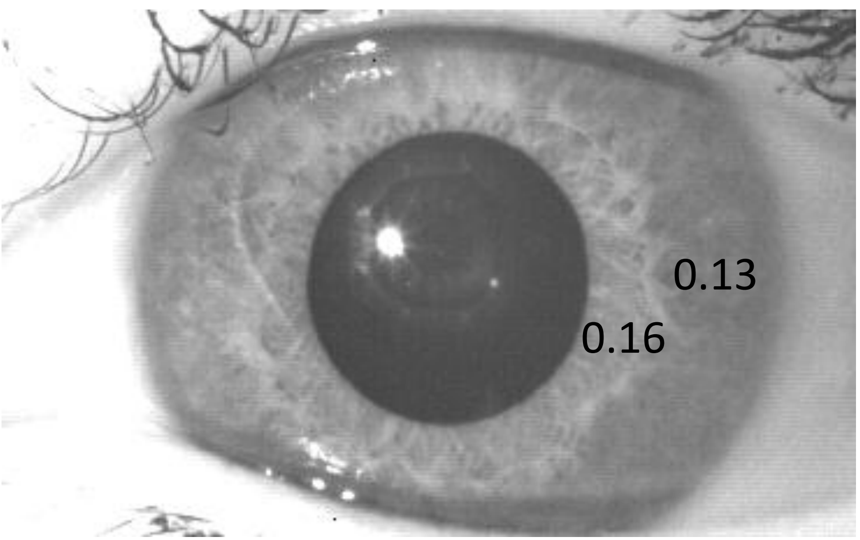
What is needed by matching algorithms?

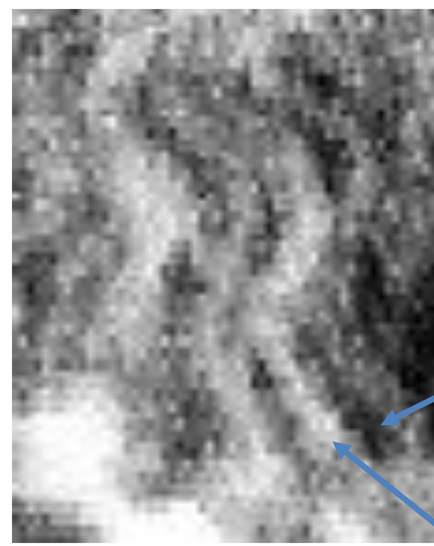
Features 0.2 - 2 millimeters?

Observed Optical Properties of the Iris: Spatially Varying Albedo

Signal-to-Noise Ratio can be expressed as a function of device variables (assuming photon noise):

$$SNR_{850nm} \sim 10 \left(\frac{\gamma_a}{0.15}\right)\left(\frac{F_i}{1mW/cm^2}\right)^{1/2}\left(\frac{a}{0.12}\right)^{1/2}\left(\frac{Q}{0.1}\right)^{1/2}\left(\frac{t}{25msec}\right)^{1/2}\left(\frac{\ell}{0.5mm}\right)\left(\frac{d}{5mm}\right)\left(\frac{D}{50cm}\right)^{-1}$$





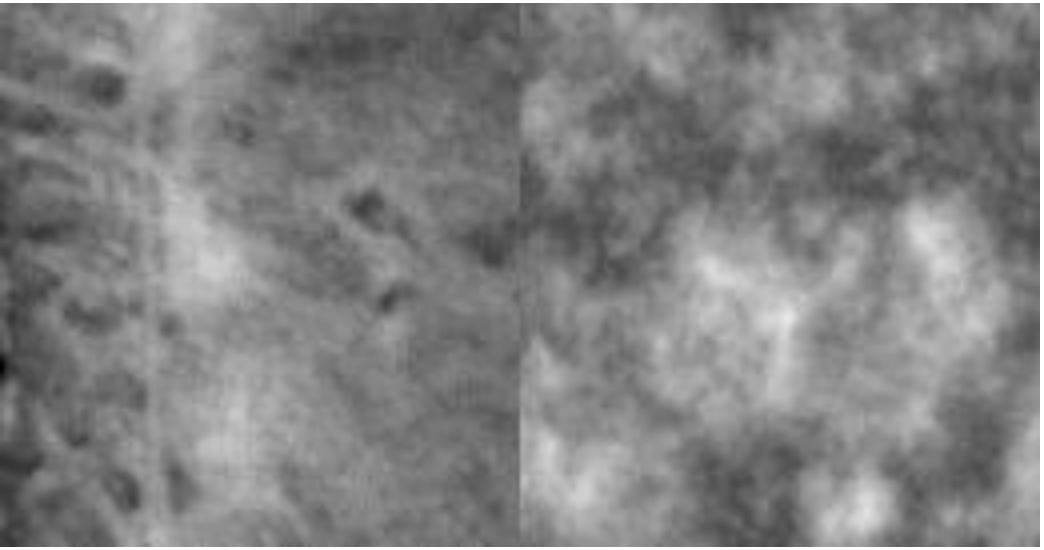
Iris Texture

$$a_{low} = a\left(1 - \frac{\gamma_a}{2}\right)$$

$$\Delta a = a_{high} - a_{low} = \gamma_a a$$

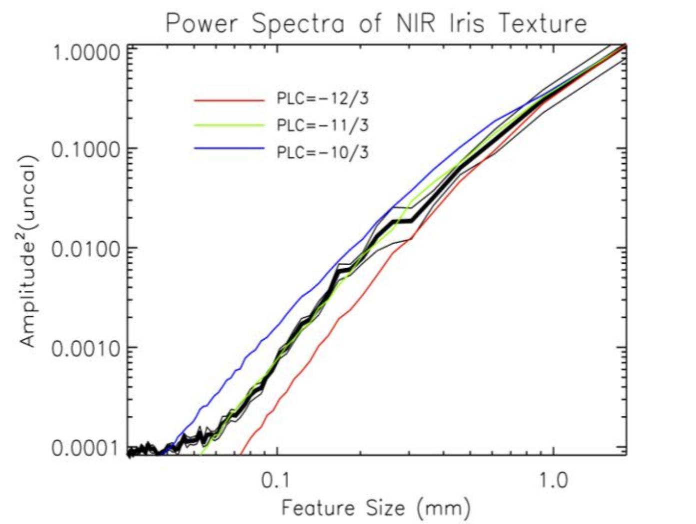
$$a_{high} = a\left(1 + \frac{\gamma_a}{2}\right)$$

Contrast Decrease with Smaller Scale

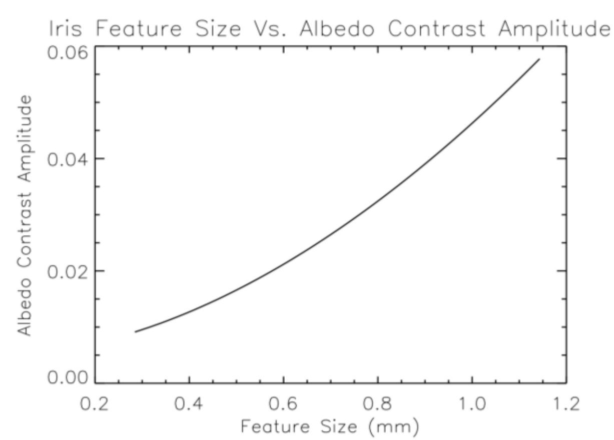


NIR Iris **3-D Kolmogorov**

Iris albedo texture seems to follow a power law distribution…



Similar to 3-D Kolmogorov Turbulence Structure



Rough Fit: $\boldsymbol{A(\mathrm{k})=C_s\,(k^2)^{-11/3}}$

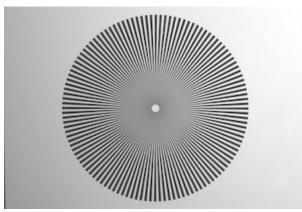
Add characteristic inner and outer scales:

$\boldsymbol{A(\mathrm{k})=C_1\,(k^2+\mathrm{k}_o^{\,2})^{-11/6}\,\mathrm{exp}(-\mathrm{k}^2/\mathrm{k}_i^{\,2})\,)\,(1-\mathrm{c}_2(\mathrm{k}/\mathrm{k}_i))}$

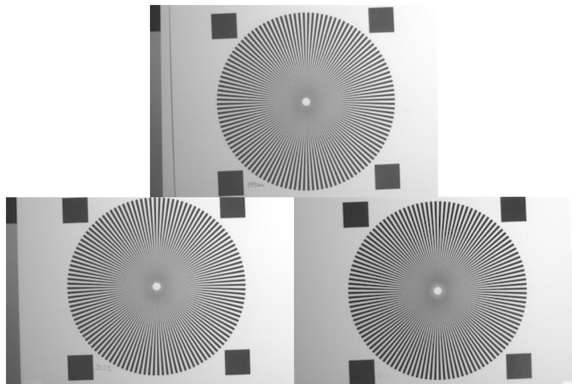
("bump" around 0.3mm)

Target Pattern Creation

Utilization of Carbon-based Ink with High Resolution Inkjet Printers

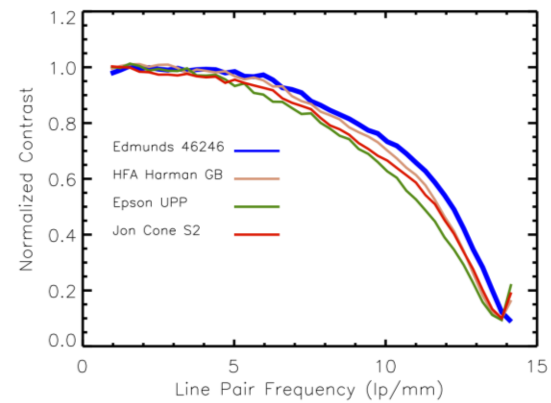


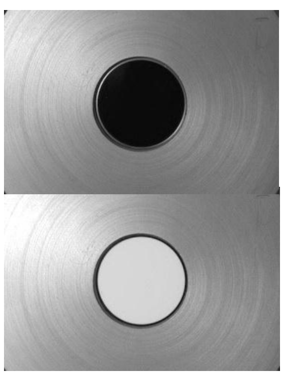
Commercial Grade Star Target



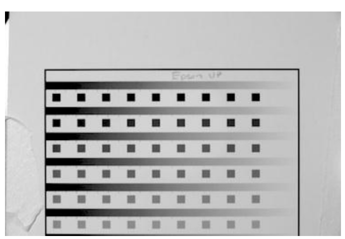
Carbon-based Inkjet Star Target

CTF Comparisons

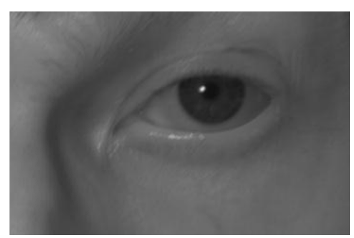




Reflectance Standards

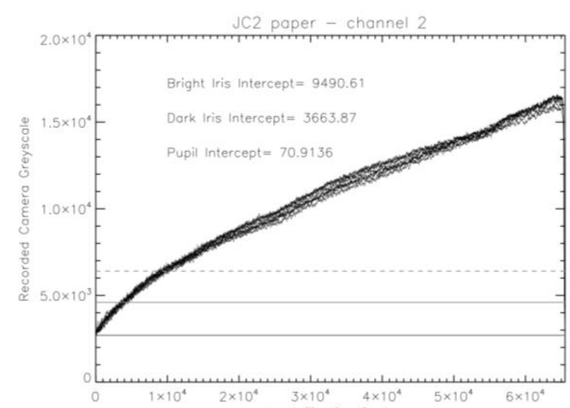


Printer Output
(16-bit Dynamic Range)

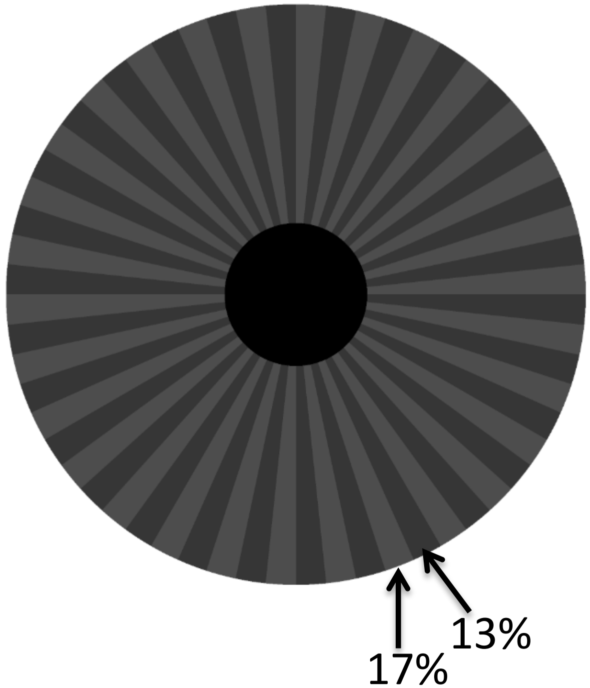


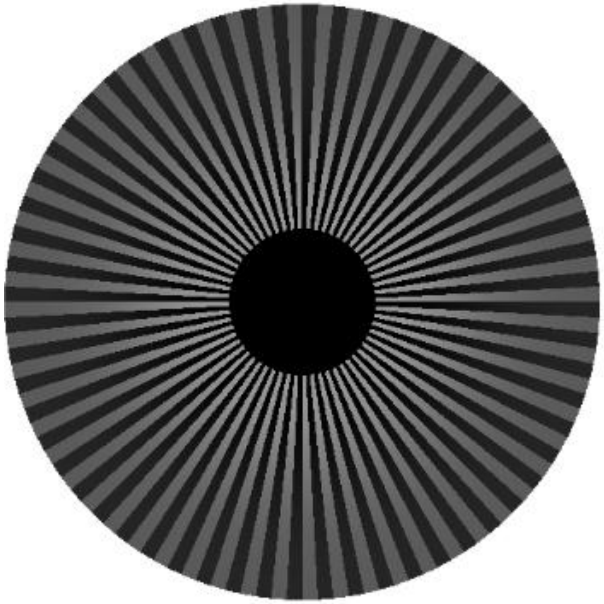
Eye Reference

16 Bit Value- Albedo Calibration



Target Overview: Star Pattern



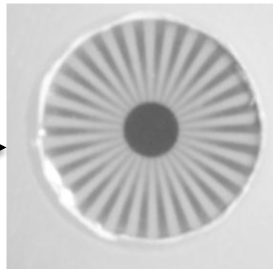


<u>MTF (Primary)</u>

- 60 segments : 0.8 – 3.5 lp/mm
- 120 segments : 1.6 - 6.5 lp/mm
- Large Areas at Frequencies = 1, 2,& 3 lp/mm
- Theta variations noted versus target rotations,
- Average over theta at given R used for Qualification Criteria

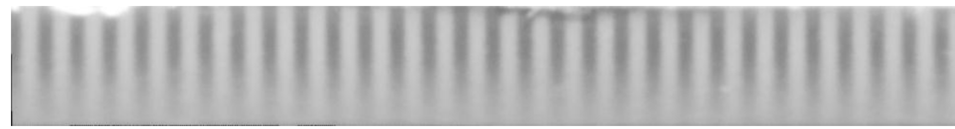
Straightforward CTF
+ Alternate encoder based metric

Collected Target Image →



→ Segment Unwrap →

Can extract CTF here



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Create Binary Template

Reference

XOR

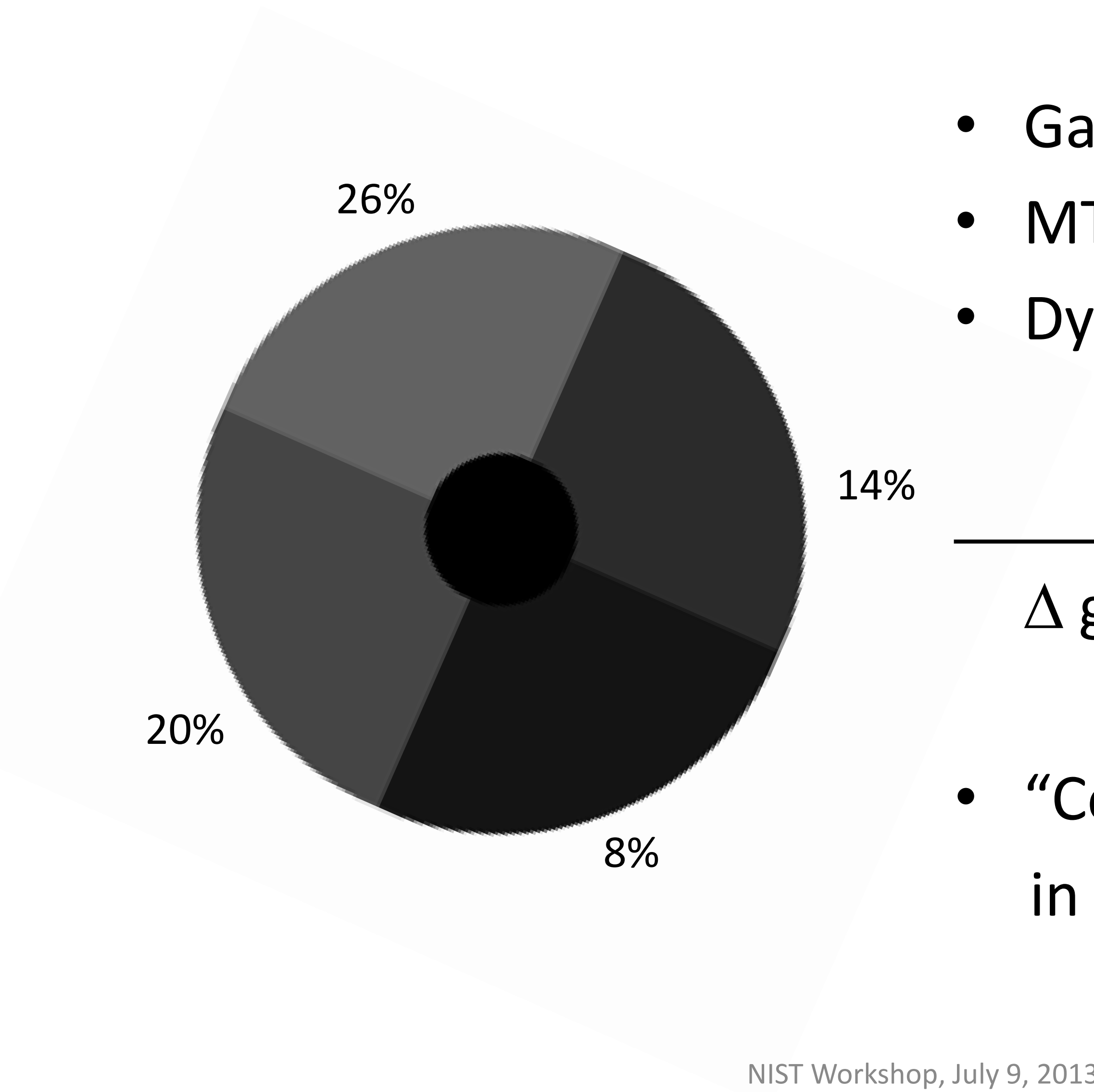
Collected

Generate
Raw Hamming Distance
Score Elements

Radius

Theta

Target Overview: Quadrant Pattern

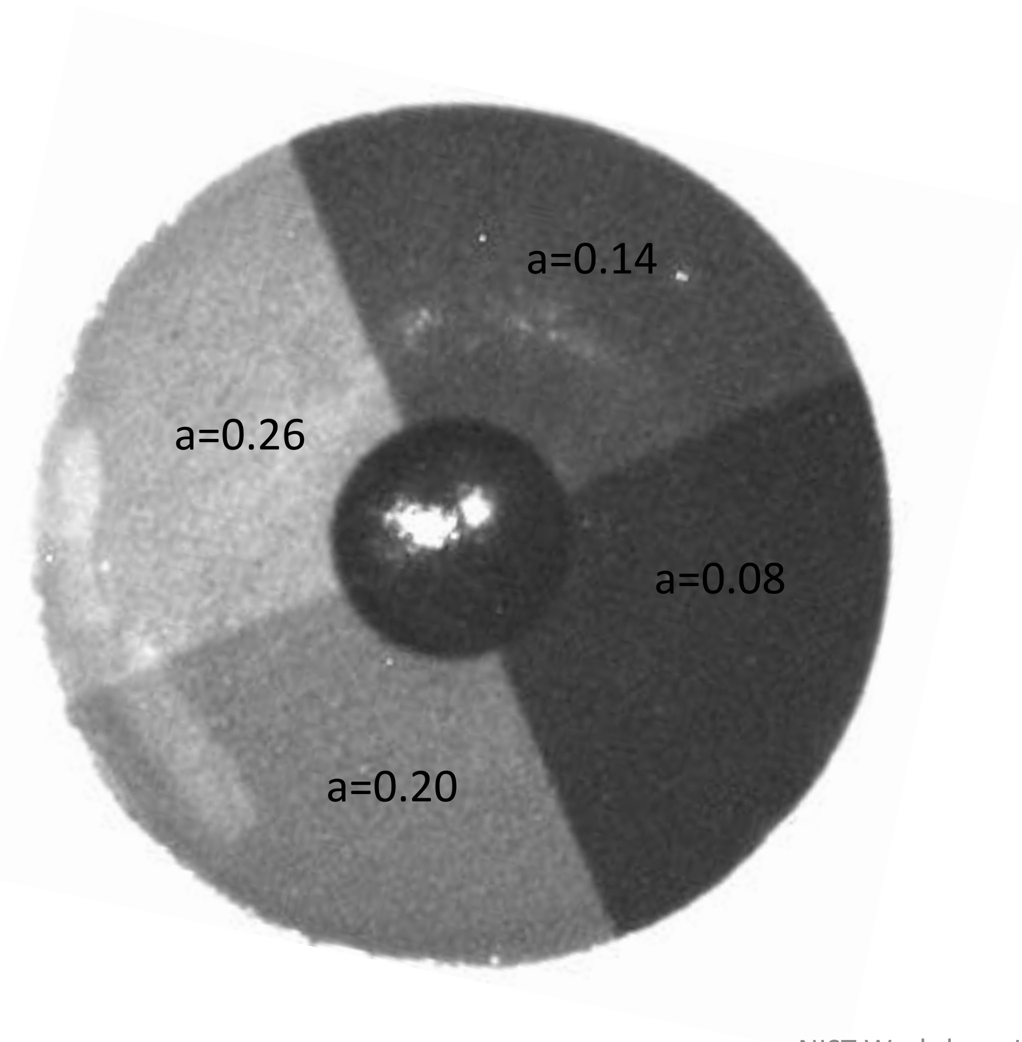


- Gain Linearity
- MTF (secondary)
- Dynamic range resolution:

$$\frac{\Delta \text{ Albedo}}{\Delta \text{ greyscale increment}}$$

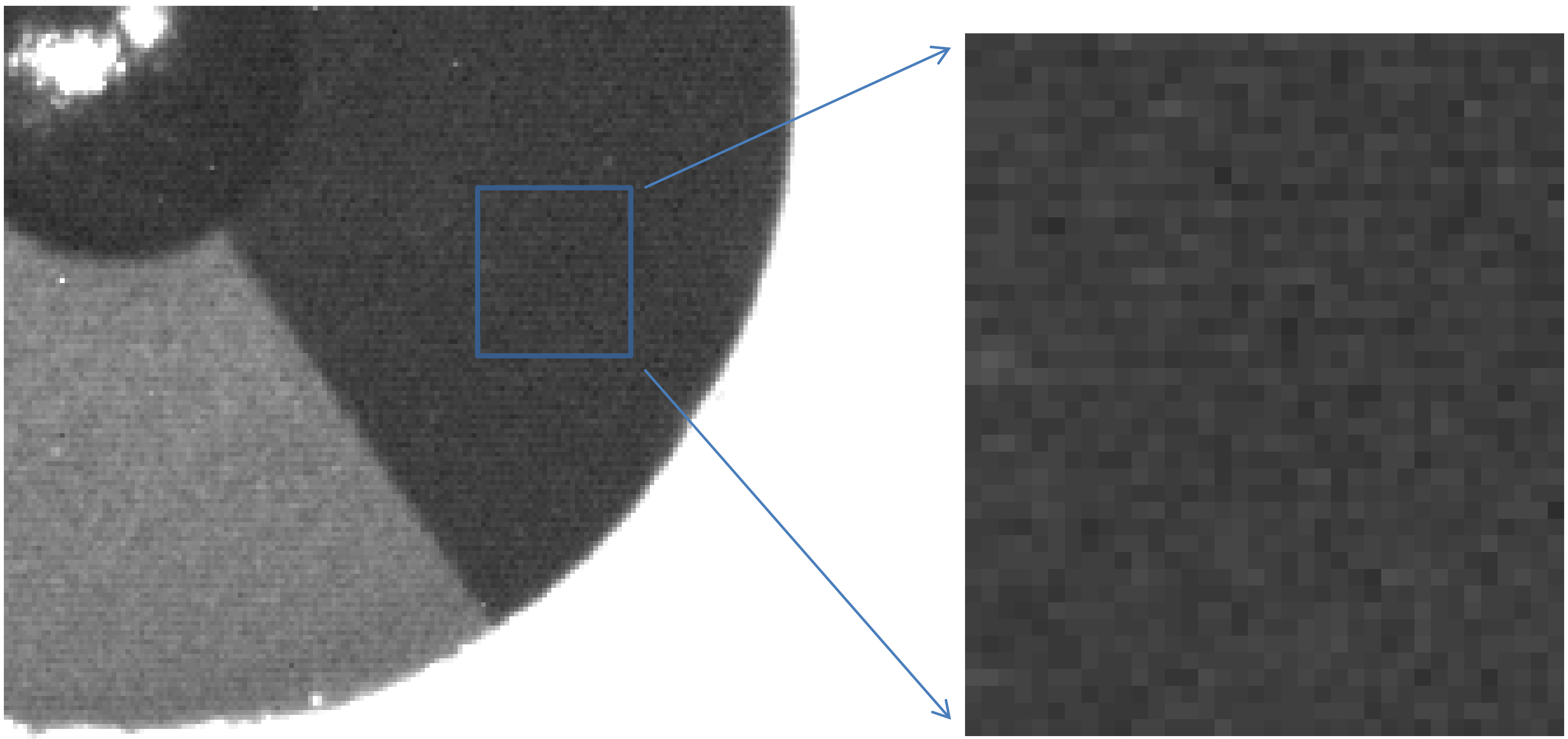
- "Conventional" SNR in each uniform region

Analysis Method: Detector Linearity



- Fit line to linear model, statistical analysis on errors
- Check systematics (specular reflections) by rotating target via test protocol

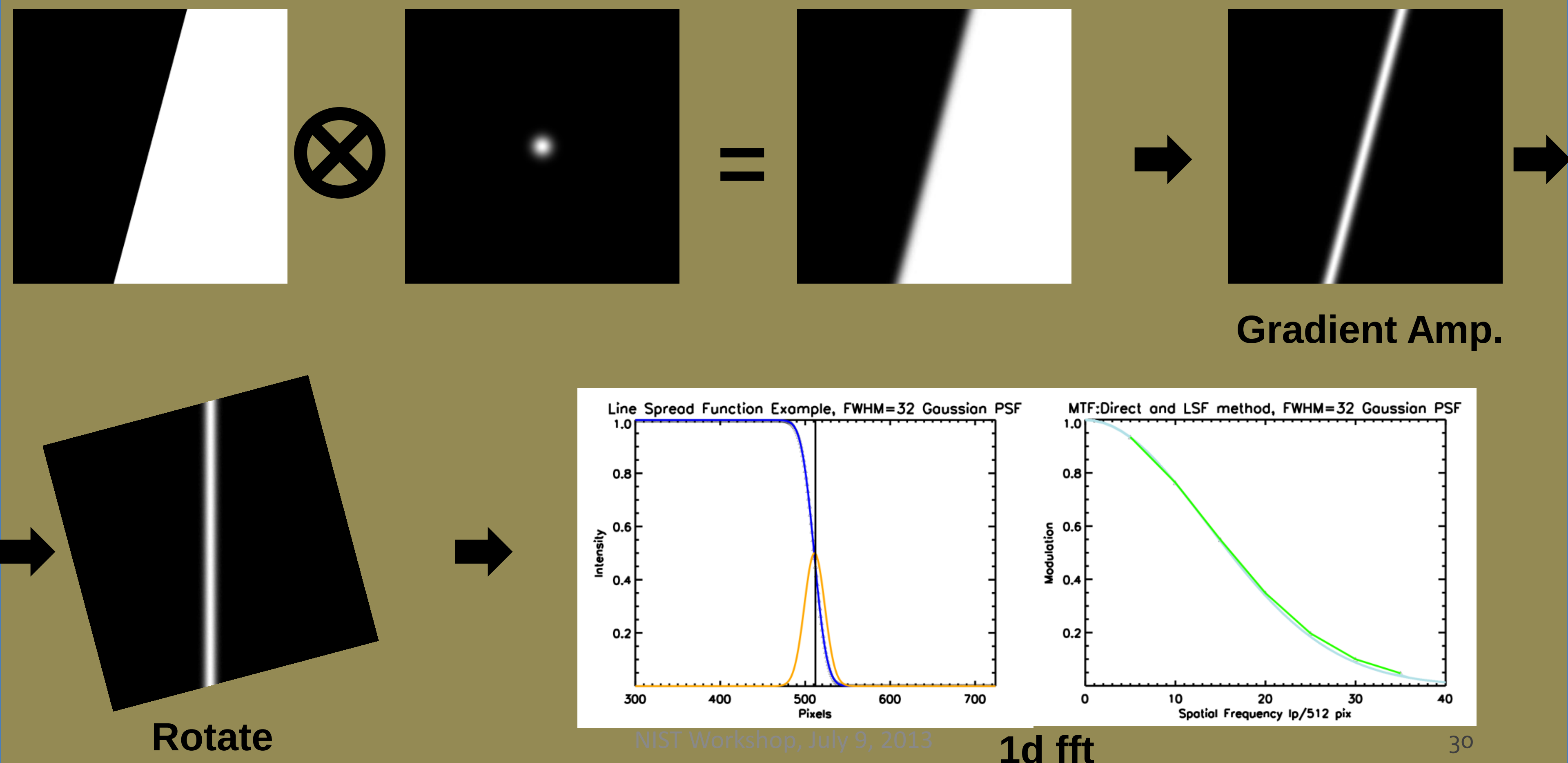
Analysis Method: Contrast SNR



- Establish Distribution Type (e.g. Gaussian)
- Calculate Standard Deviation versus cell size and albedo
- Use (hopefully) Gaussian Statistics for simplicity (i.e. 1,2,3.. Sigma Vs. feature type)

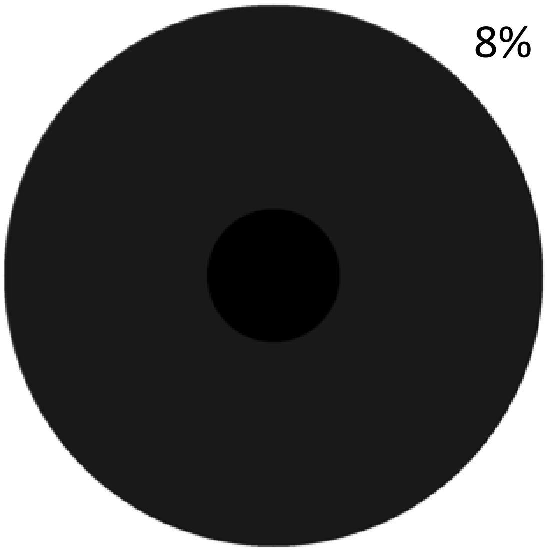
Slanted edge MTF extraction (secondary)

ISO 12233 slanted edge test

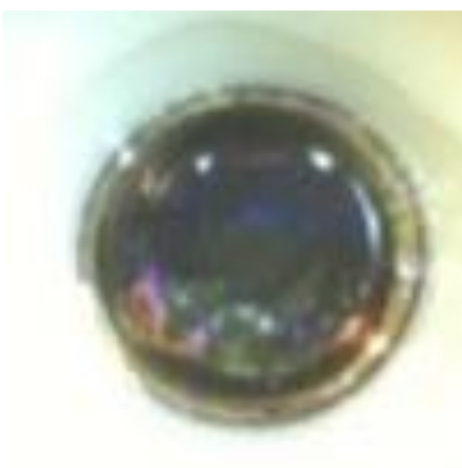


Target Overview: Uniform Dark

8%



Uniform Dark

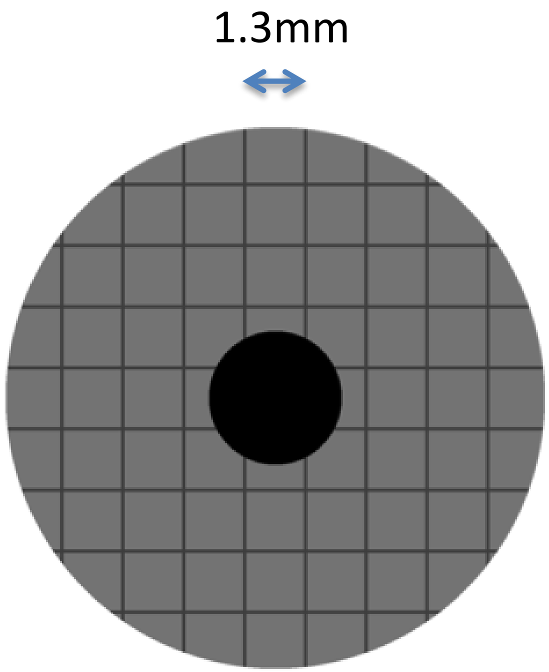


<u>For Illumination Characterization</u>

- Device Illumination pattern
  - Nose/eye socket reflections
  - Primary Corneal reflection pattern

    (any overlap with iris?)
- Ambient light Mitigation

Target Overview: Distortion Grid

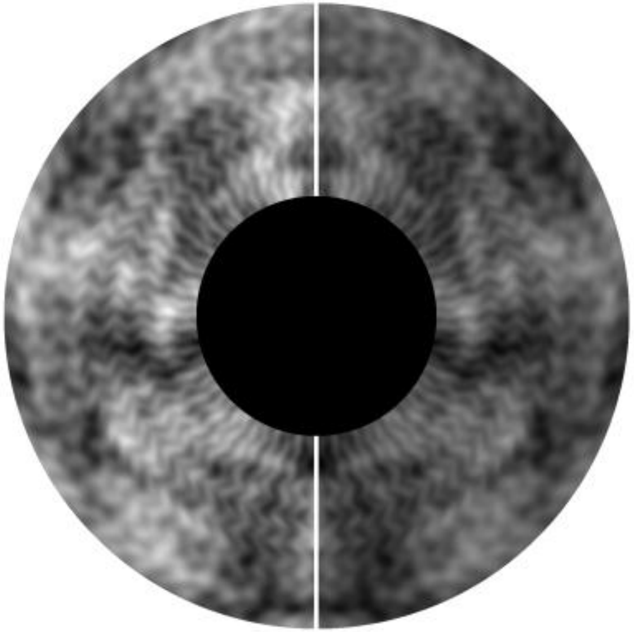


Distortion Grid

<u>Used to map field distortion</u>

- Stated in object plane Cartesian coordinates
- Measurements relative to pupil center coordinates with average pixel scale from limbus radius
- Grid of error values relative to perfect model

Target Overview: Iris Feature Spectrum

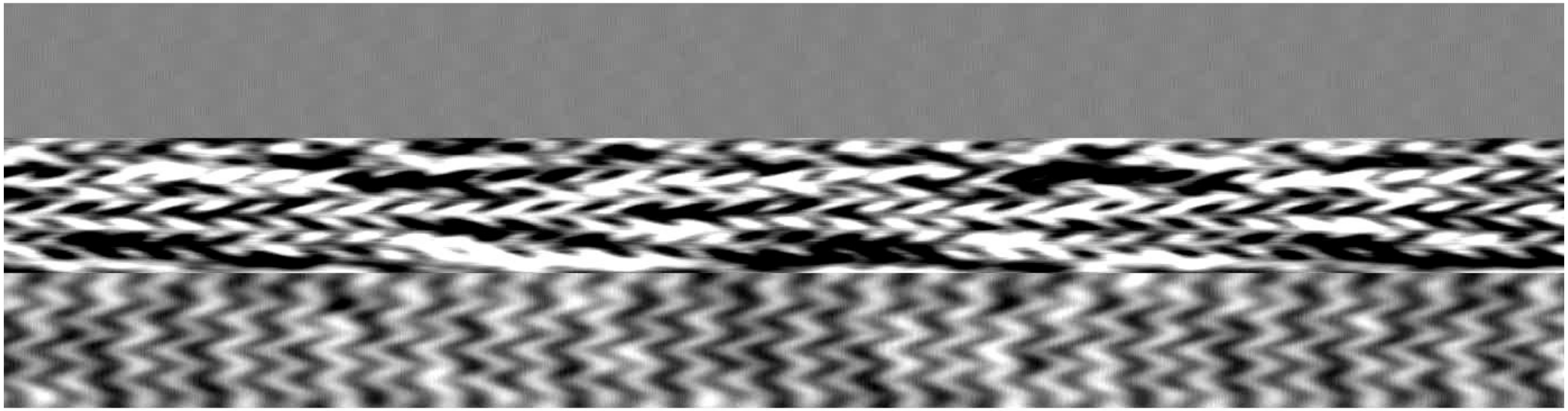


- Calibrated to have average albedo of ~0.16 at 800nm
- -11/3 feature spectrum
- A bit more power in theta

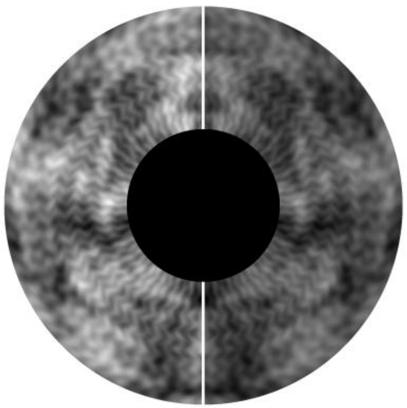
Encoding Example

Psuedo-Polar Normaized

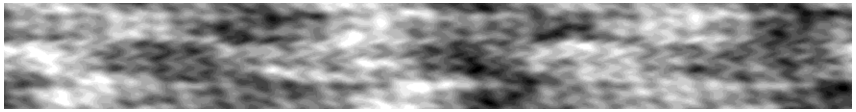
Encoded signal (3 Haar filters varying Spatial Freq. to make cube)



Binary Encoder/ HD Metric



Normalized Image (PRISTINE)



Normalized Image (Collected)

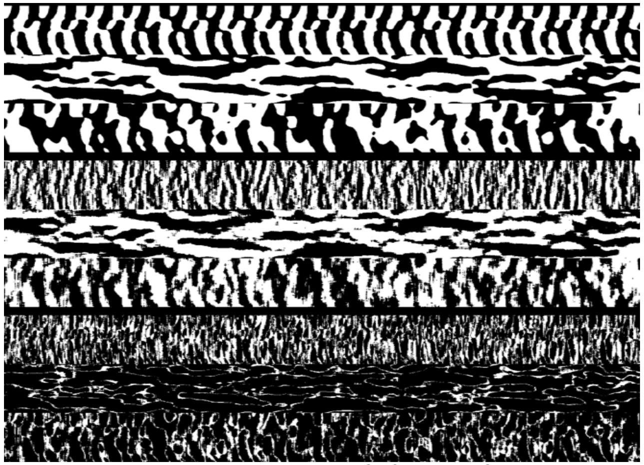
High Frequency

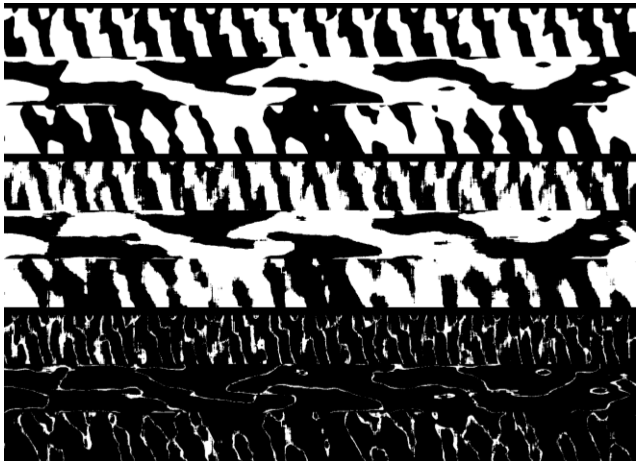
Middle Frequency

Template (PRISTINE)

Template (Collected)

XOR RESULT





Discussion: Target Patterns

- Any obvious sources of biases?
- Realism of the Iris Texture Target – Method of the -11/3 power law
- Definition of “pristine” template
- Is one iris texture target enough?
- No explicit measurement of the Phase Transfer Function
- No 3-D surface topology taken into account – (illumination angle matters)

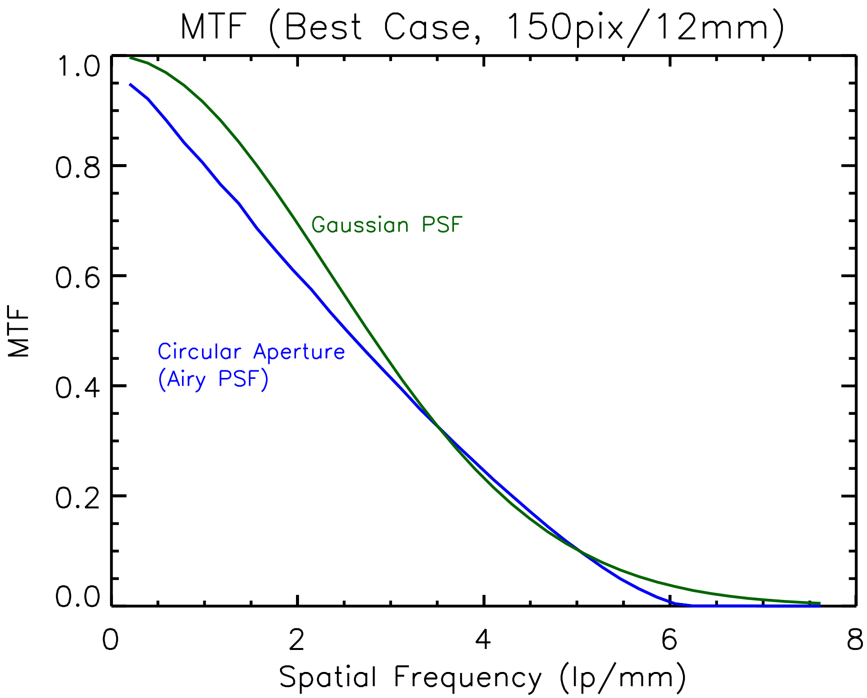
Other Measurements

- Exposure Time Test
  - Ring of fiber fed LEDs mounted in eye target, blinking in series with 5ms pulses. Exposure time is estimated by the number of lit fibers seen in an image.
- Eye Safety
  - Calibrated Irradiance meter (1 KHz large area photo-diode) embedded in eye target
- Wavelength Characterization
  - Multiple captures with fiber fed USB spectrometer with probe mounted in eye target

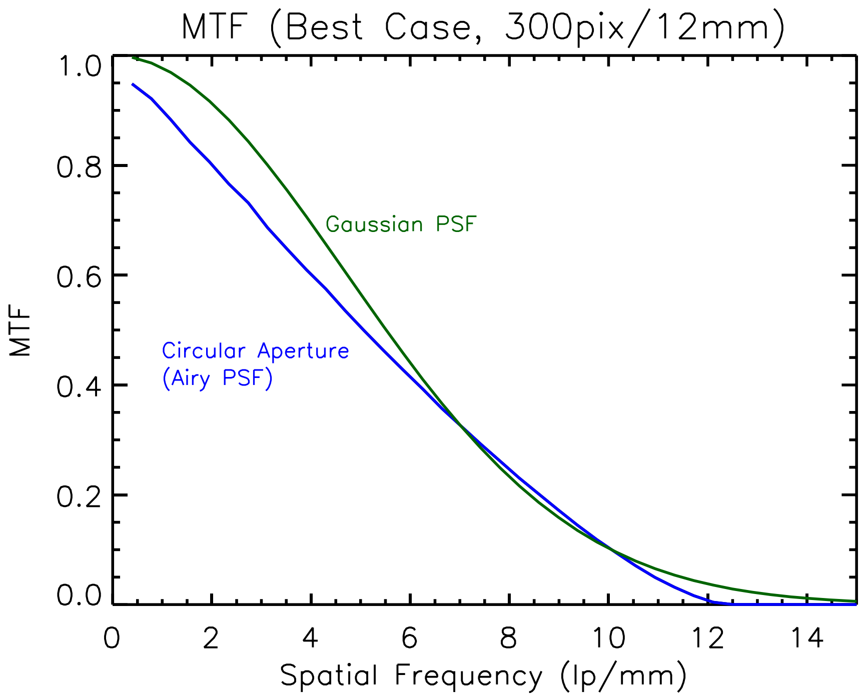
Discussion: Other Measurements

- Wavelength Guidelines in NIST Mobile ID Best practices Document is not backed by available study
- Wavelengths used may be trade secret
- Reference to use for Eye Safety
- No allowance for wavelengths other than 700nm-900nm

Best Case MTF with Typical Sampling



50% mod @ ~2.5 lp/mm



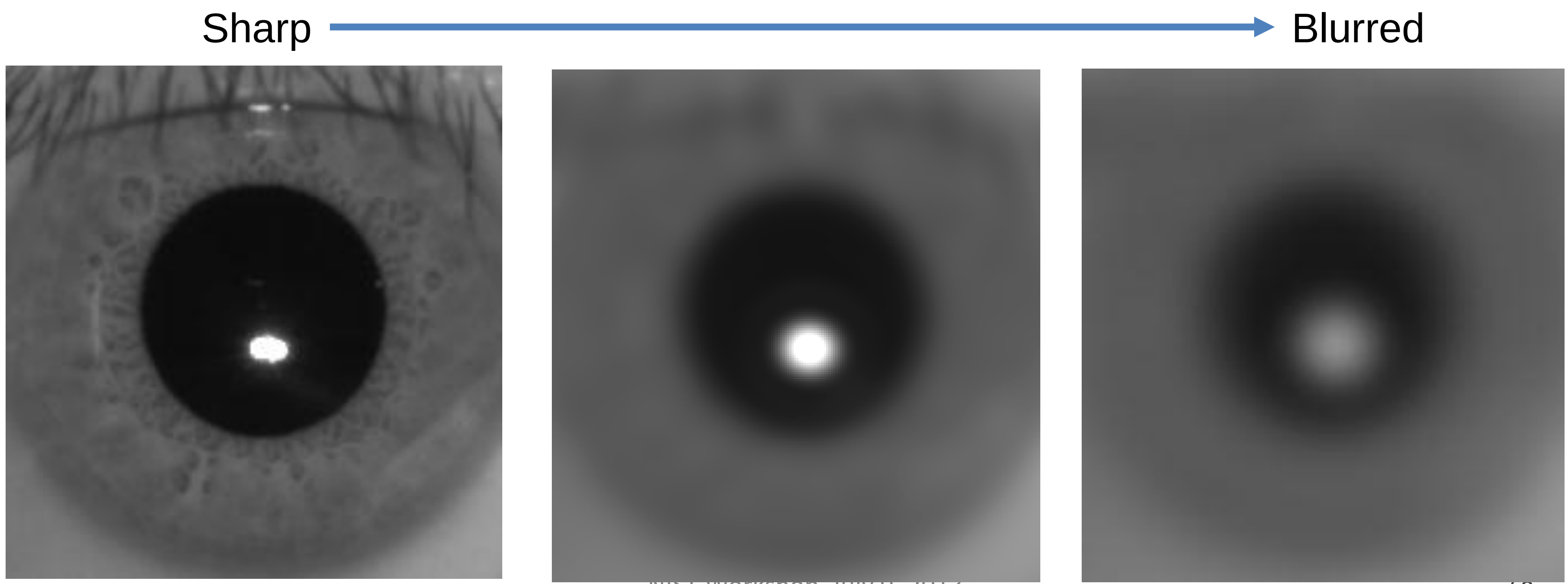
50% mod @ ~5 lp/mm

Examples from Best Case Diffraction Limited Conventional Optics (No Deconvolution)

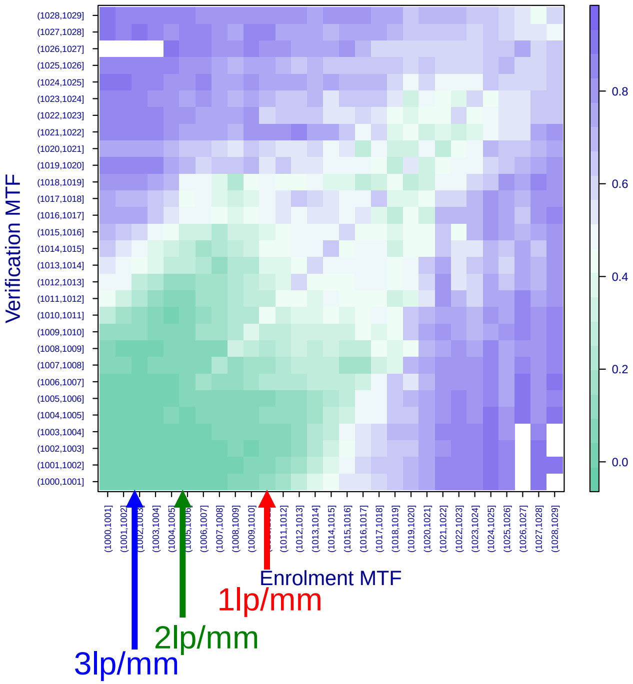
MTF "Controlled" Study

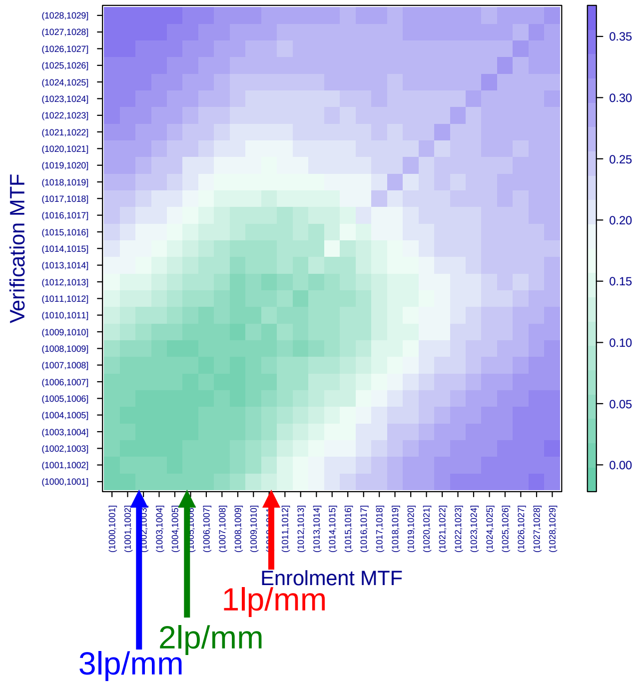
Degraded University of Bath Images:

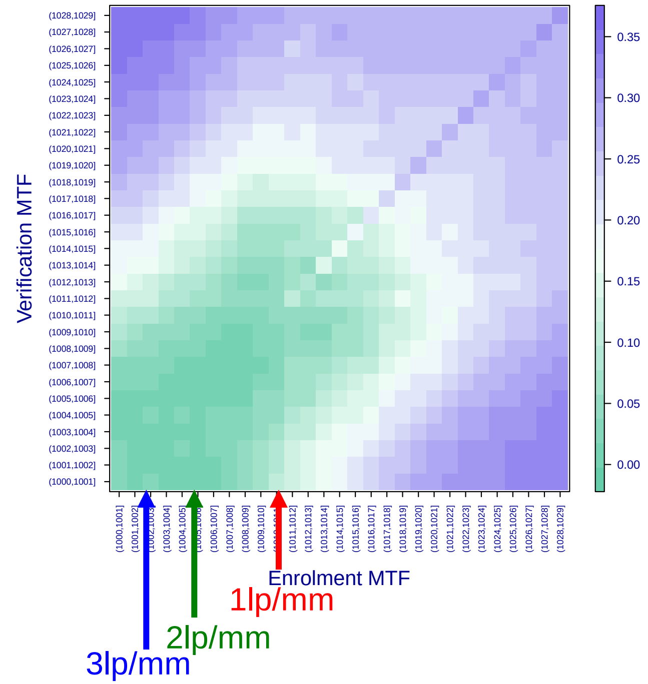
- Convolution with Gaussian and Airy Function Blur Kernels
- Scaled relative to iris diameter
- 30 samples, ranging from FWHM ~ 0.07mm – 1.3mm (~50%@ 6 - 1/3 lp/mm)



Blackbox Results from NIST







Arrows indicate rough 50% modulation at 1,2,3 lp/mm

Color indicates score averages in bins (green match, blue mismatch)

3 Qualification Levels

Level 1 **(Opens up applications for Small N, 1-1)**

- Measured MTF of 50% at 1 lp/mm using the IDQT targets.
- HD of 0.1 or less using 0.75mm feature encoders to the pristine reference template for at least 95% of the collected images, >90% pass mask

Level 2 **(Similar to old guideline, suitable for large N)**

- Must pass level 1, and 50% modulation @2 lp/mm, feature size of 0.38mm.

Level 3 **(Placeholder for Future*, indicates very high SNR for level 1 and 2 feature sizes)**

- Must pass level 1,2, and 50% mod @3 lp/mm, feature size of 0.25mm.

NOTE: Other metrics still reported, and used to assess the potential root cause of a possible failure. All levels must be eye safe.

*studies not published, still we have confidence that information density is high at 0.25mm scales.

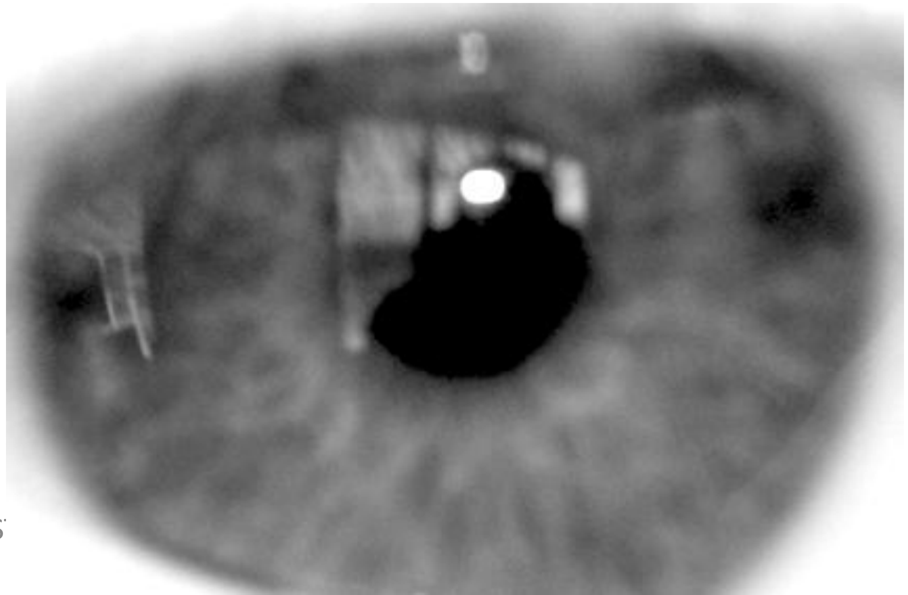
Three Ambient Light Levels

Ambient Light Scenario	Lux Reading (Human Response)	NIR Irradiance (700-900nm) mW/cm^2
Indoor, no Sunlight through glass	50-500	~1.e-3
Indoor, sunlight through glass (same as outdoor in shade)	2500-5000	~1.e-2
Outdoor (consider outdoor shade+ outdoor)	25000-50000	~0.1

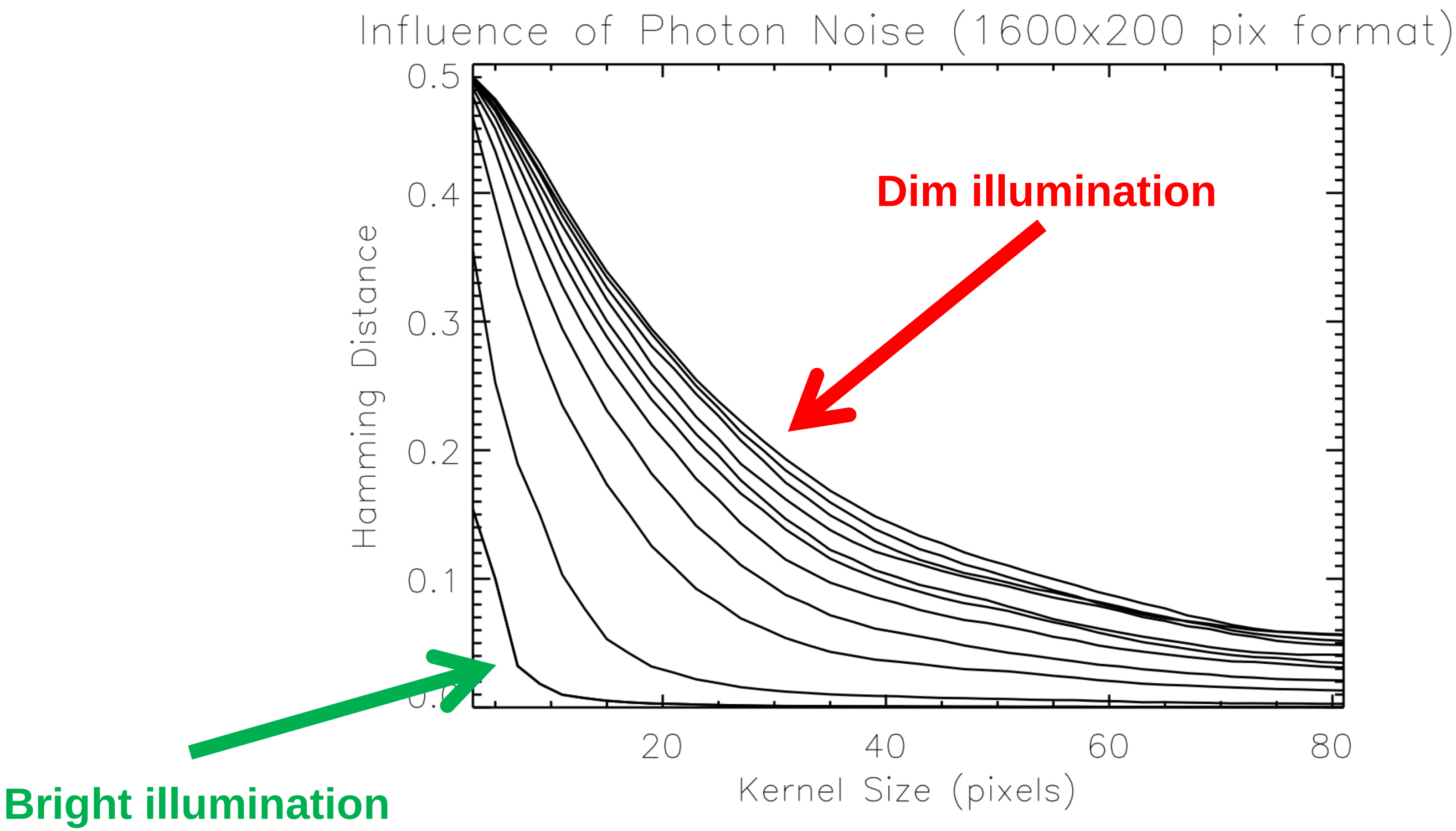
Proof of concept finished

Process currently being worked out to make this test practical…

Contrast structure of surrounding scene structure makes a difference.



Other tests possible (but needed?): Influence of photon Noise



High Frequency **Low Frequency**

List of “nice to have” studies

- Ultimate: large, diverse human subject collection with multiple devices, multiple wavelengths, and manually controlled device to enable global exploration of all likely important device related covariates
- Multi-wavelength data collection with many narrowband samples within the 700-900 nm region for meaningful interoperability guideline
- Effect of illumination angle: 3-D structures

Discussion: Qualification Criteria

- Should Qualification include specific criteria on more than iris feature spectrum and MTF targets?
- Are the 3 levels 1,2,3 lp/mm too closely spaced in spatial frequency response, to broad?
- Why chose 0.1 for the Hamming distance criteria?

Acknowledgements

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Homeland Security

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